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# Performance and emission characteristics of compression-ignition engine handling biodiesel blends with electronic fumigation

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## Abstract

Many research works are being carried out to enhance the performances of internal combustion engines to meet out the current energy demand and to reduce the emission with the alternate fuels. In this experimental investigation, the performances and emission characteristics of compression ignition engine were studied by using electronic fuel fumigation method. The lemongrass biodiesel blended with 20% of biodiesel and 80% of diesel (B20) was used as primary fuel and 1-propanol is used as secondary fuel for fumigation. The Kirlosker, single cylinder four stroke, direct injection, and water cooled engine was taken for conduction of tests. The speed of the engine is maintained constant and the engine load was varied in the range of 0%–100% and fumigation injection timing is varied in the range of 1 ms, 3 ms and 5 ms to study the engine parameters. It is studied that the brake thermal efficiency of fumigation fuel at 5 ms is 6.7% higher than diesel and at 3 ms is 3.1% higher than the diesel fuel at 100% load. The specific fuel consumption at 5 ms is 16 % higher than the reference diesel fuel. The 5 ms 1-propanol fumigation produces the maximum HC and CO with minimum smoke and NO because of lower combustion

temperature and incomplete combustion. The SFC of fumigation fuel at 5 ms is 18.6% higher than diesel at 100% load and 23 % higher than diesel at 80% load. The net heat release of fumigation fuel (1-propanol) at 1 ms produces 2% higher than the reference diesel at crank angle of 360°. The fumigation fuel (1-propanol) injection timing at 5 ms produces more percentage of CO at different load conditions. It is also studied that the minimum level of CO is 0.38 % at 40% load condition. The fumigation fuel at 5 ms injection timing produces minimum percentage of CO<sub>2</sub> at different load conditions. The minimum level of CO<sub>2</sub> is 9.3% at 80% load condition. The other emissions are also analyzed and recorded the levels based on the load condition.

Keywords: Mechanical engineering, Energy, Petroleum engineering

## 1. Introduction

Diesel engines are playing significant role in the road transport and power generation. The diesel fuel crisis is the reason for carrying out the research on alternative fuels. The research on internal combustion engine modification, alternate fuels, dual fuels and renewable energy sources are the hot topic to meet out the today's energy demand. Most of the researchers suggested the alternative energy sources such as vegetable oil [1] and animal fat [2]. The Biodiesel extraction out of vegetable or animal fat is a very big problem due to the availability and transesterification [3, 4]. However, use of biodiesel in internal combustion engine makes a significant impact on diesel engine combustion [5] due to lower combustion temperature and higher viscosity [6]. The transesterification reactant also makes significant role on engine performance and emission [7]. The biodiesel emission depends on oxygen content present in biodiesel molecules [8] and fuel bond. More oxygen produces higher NO [9] and lower CO and lower oxygen produces lesser NO and higher CO [10]. Most of the biodiesels produce higher NO [11], lesser brake thermal efficiency (BTE) due to lower oxygen content, lower calorific value and higher specific fuel consumption (SFC) [12], therefore many researchers concentrated to improve the biodiesel efficiency, improve the quality of combustion and emission reduction. Different performance enhancement techniques have been used by different researchers such as oxygenated fuel additives, different compression ratio, injection pressure [13], fumigation [14] and injection timing [15] etc. Some of the researchers concentrated on emission reduction techniques such as exhaust gas recirculation (EGR) [16], water emulsion [17] and selective catalytic converter [18]. Normally NO and smoke particles are considered as the major pollutant from diesel engine exhaust. Researchers proposed some of the mechanisms for NO formation such as Zeldovich mechanism, Fenimore mechanism, fuel NO<sub>x</sub> mechanism, N<sub>2</sub>O pathway mechanism and the NNH mechanism [19].

The availability and extraction of lemongrass biodiesel are easy and cheap in South India and direct transesterification method is used to produce biodiesel [20]. Lemongrass biodiesel has higher viscosity, lower cetane number and lower heating values. However, the combustion of biodiesel is very closer to the result of diesel combustion [21]. Moreover the lemongrass combustion characteristics are closer to the diesel fuel combustion. The diesel blend with 1-propanol produces maximum heat release and peak pressure [22] and lesser NO, smoke [23]. A little attention has been shown on the use of alcohol in CI engines. This is because of the drawback caused by the alcohol in diesel engines such as higher mass and volume requirement of alcohol, difficulty of large amount of alcohol with diesel, unstable blends, low cetane number and poor auto ignition capability [24]. Therefore, many techniques have been used in diesel engines to improve the engine performance, in particular, the dual fuel operation, alcohol + diesel. The widely used methods for achieving dual fuel operation are [25]: 1) Alcohol fumigation: the supplying of alcohol to the intake air charge. 2) Dual injection: injecting two different fuels separately, 3). Alcohol + diesel fuel blend: mixing of fuels before injecting, 4). Alcohol + diesel fuel emulsion: using an emulsifier mixing of fuels.

Fumigation is a technique which is suitable to improve the engine combustion and reduce the emission. Fumigation is a method by which the fuel to be fumigated is sent to the engine by carbureting, vaporizing or injecting the into the intake air stream. It needs additional carburetor, vaporizer or injector with a separate fuel tank, fuel lines and control systems. The alcohol fumigation technique results a significant reduction in carbon dioxide CO<sub>2</sub> up to 7.2%, oxides of nitrogen (NO<sub>x</sub>) up to 20% and particulate matter (PM) up to 57%. The increase in carbon monoxide (CO) and hydrocarbon (HC) emission is the undesirable effect of using alcohol fumigation. Alcohol fumigation improves the BSFC as the heat of vaporization of fuel is higher whereas, the brake thermal efficiency is decreased at low engine load and is increased at higher engine load [26]. Advantages of fumigation are: 1) it requires a minimum of modification to the engine, 2) the easy switch over of engine from dual fuel to diesel fuel operation and vice-versa, 3) the easy flow control of the fuel with simple device and fuel supply system. 4) improves the power output and reduces the emissions. The effects of gasoline fumigation has been experimentally investigated in a single cylinder direct injection diesel engine [27] and reported that the fumigation increases the efficiency and decreases the specific fuel consumption. Fumigation makes effective combustion and reduces the ignition delay [14, 26, 27, 28, 29]. The thermal efficiency increases due to fumigation [29]. It is found that the NO<sub>x</sub> concentration decreases in all the tested conditions.

It is studied from the literature that only a little attention has been shown on the performance of IC engine handling biodiesel (B20) and 1-propanol by varying the fumigation injection timings. Therefore in this experimental study, the performance and emissions of four stroke single cylinder diesel direct injection diesel engine are

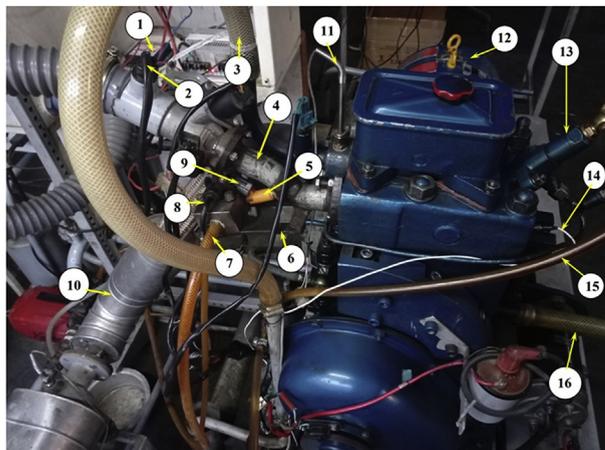
analyzed by using lemongrass biodiesel (B20) blended with 20% of biodiesel and 80% of diesel as primary fuel and 1-propanol as the secondary fuel for fumigation at three injection timings.

## 2. Experimental

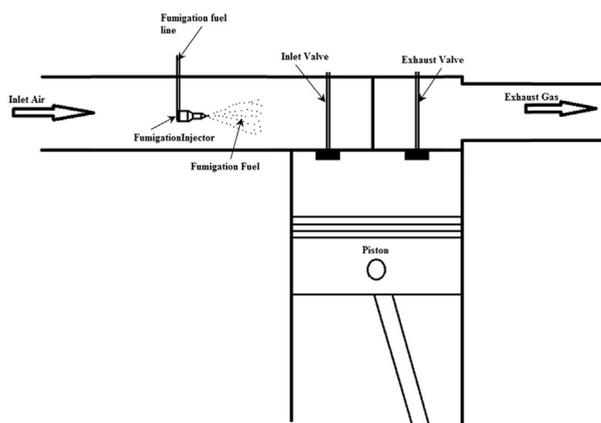
### 2.1. Materials & methods

Fig. 1 shows the photograph of experimental test rig and Fig. 2 shows the schematic diagram of fumigation method. The test set up consists of Kirlosker, single cylinder four stroke, direct injection, and water cooled engine, SAJ test plant, AG10 eddy current DC dynamometer with APEX make, constant speed, 230 V loading unit, fuel flow meter, and exhaust gas analysis systems. Table 1 gives the engine specifications. Dynamometer is used to measure the engine torque and speed. The fumigation fuel injector is connected with ECU and the ECU controlled by programs which are operated numerically. The Maruthi 1000 model fuel injector is used to inject the fumigation fuel. The amount of fuel consumed is calculated by using fuel meter which is connected by the mass burette and chronometer. K-type thermocouple is connected to the digital display unit to measure the exhaust gas temperatures. The timings are measured by the electronic control unit (ECU) attached with the test rig and fuel injection timing is controlled by APEX innovation software solutions.

Emissions (HC and NO in ppm, CO, CO<sub>2</sub> and O<sub>2</sub> in percentage volume) are measured by an AVL 473C exhaust gas analyzer and smoke opacity (in percent) is measured by the AVL smoke meter. The specifications of the exhaust gas analyzer and smoke meter are given in Table 2. AVL 473C determines the emissions of CO



**Fig. 1.** Photograph of the experimental setup. 1. ECU, 2. Air flow measuring sensor, 3. Engine cooling water outlet, 4. Inlet Manifold, 5. Electronic fumigation injector, 6. Fumigation injector bed, 7. Fumigation fuel inlet, 8. Fumigation fuel return line, 9. ECU signal connections, 10. Exhaust gas pipe line, 11. Cooling water temperature sensor (out), 12. Eddy current dynamometer, 13. Primary fuel injector, 14. Pressure sensor, 15. Primary fuel return line, 16. Engine cooling water inlet



**Fig. 2.** Schematic diagram of fumigation of fuel.

**Table 1.** Engine specifications.

Particulars	Specifications
Manufacturer	Kirloskar
Type	Four stroke, single cylinder, Direct injection, VCR engine
Bore	87 mm
Stroke	110 mm
Compression ratio	18:1
Engine speed	1500 RPM
Fuel injection pressure	210 bar
Injection timing	23° BTDC
Cooling system	Water cooled engine

and HC by infrared measurement method (Non-dispersive infra-red) and NO is by electrochemical sensors. The properties of the fuels used in this study are presented in Table 2. Diesel is mixed with lemongrass for 5 minutes with stirrer for complete mixing and it is observed that no homogeneity problem is seen with the fuel blends. The accuracy of the instruments and uncertainty of the computed results of the parameters are given in Table 3.

**Table 2.** Fuel properties.

Properties	Diesel	Lemon Grass	1-Propanol
Viscosity at 40 °C Cst	3.25	4.18	2.8
Density kg/m <sup>3</sup> at 15 °C	835	984	803
Cetane Number	50	38	15
Flash Point	>52 °C	150 °C	22 °C
Auto Ignition Temperature °C	>250 °C	-	371
Heating Value MJ/kg	44.8	36.27	30.68

**Table 3.** Uncertainty and measuring range of gas analyzer and smoke meter.

S.No	Parameters	Accuracy
1	Airflow	0.6481 %
2	Fuel flow	0.7319 %
3	Engine Power	0.9434 %
4	Exhaust gas Temperature	±5 °C
5	Viscosity	0.7 %
6	Cylinder Pressure	0.61644 %
7	Brake power	1.087%
8	Fuel consumption	0.25%
9	Friction power	0.25%
10	Brake thermal efficiency	1.116%
11	CO	±0.03 %
12	CO <sub>2</sub>	±0.5 %
13	HC	±10 ppm
14	O <sub>2</sub>	±5 %
15	NO	±10 ppm
16	SMOKE	±1 %

## 2.2. Experimental procedure

Initially, the tests are conducted by using diesel fuel to generate the reference line data and B20 (20% lemongrass biodiesel mixed with 80% diesel). The speed of the engine is maintained constant (1500rpm) and the engine load is varied in the order of 20%, 40%, 60%, 80% and 100%. The corresponding temperatures and fuel consumption are recorded. Then, the exhaust gas emission and smoke tests have been done by AVL 473C exhaust gas analyzer and AVL smoke meter. The AVL 473C exhaust gas analyzer is calibrated with the atmospheric air. AVL smoke meter is made ready for steady state condition by switch on the heater and waited for 5 minutes to reach 50 °C as recommended by the supplier. The corresponding readings are recorded for analysis. The scheme of the fumigation process is given in Fig. 2. The fumigation is done by supplying the fuel through the inlet manifold. The fuel atomizes and mixes with the air sucked in and then it goes to the engine cylinder. Then, the tests based on fumigation have been conducted with the target fuel B20 and 1-propanol (the lemongrass biodiesel blends with 20% of biodiesel and 80% of diesel as primary fuel and 1-propanol as the secondary fuel for fumigation) at 20%, 40%, 60%, 80% and 100% loadings by maintaining constant speed (1500rpm) and with 1 ms fumigation injecting timing. The corresponding readings for performance and emissions are recorded for analysis. Similarly, the tests have been conducted with 3 ms and 5 ms fumigation injection timings by maintain the

conditions applied for 1 ms test. The fuel injection timing is set and controlled by computer software APEX innovation computer software. The separate fuel tank is prepared for fumigation fuel supply and fuel measuring meter is attached with fuel supply system.

Table 3 shows the uncertainty of different devices and instruments. Most of the research works on fumigation have been done with the injection timings range of 1 ms–5 ms. However, on experimenting, it is observed that the 0 ms fumigation injection timing did not show significant results and injection timing more than 6 ms showed knocking tendency by hearing metallic sound with zig–zag pressure rise. Therefore the test on 0 ms and 6 ms injection timing has not been taken for analysis.

### 2.3. Data analysis

The brake power, fuel consumption, fuel power, brake thermal efficiency and brake specific fuel consumption are calculated by Eqs. (1), (2), (3), (4), (5) and (6).

Brake Power, BP:

$$BP = \frac{2IINT}{60} \quad (1)$$

Fuel consumption FC:

$$FC_{diesel} = \frac{(0.83 \times 10)}{(t \times 1000)} \quad (2)$$

$$[FC_{Total} = FC_{diesel} + FC_{fumigation}] \quad (3)$$

Fuel power FP:

$$FP_{Total} = (FCXC_V)_{diesel} + (FCXC_V)_{fumigation} \quad (4)$$

Brake Thermal Efficiency, BTE:

$$BTE = \frac{BP}{FP_{Total}} \quad (5)$$

Specific Fuel Consumption, SFC:

$$SFC = \frac{FC_{Total}}{BP} \quad (6)$$

Where, N is the speed of the engine in rpm, T is the torque in Nm.

### 3. Results & discussions

In this investigation, the performance and emission characteristics of compression ignition engine (The Kirlosker, four stroke diesel, single cylinder, Direct injection, water cooled engine) have been conducted by using fumigation method with the lemongrass biodiesel blended with 20% of biodiesel and 80% of diesel B20 as primary fuel and 1-propanol as the secondary fuel for fumigation. The exhaust gas emission and smoke tests have also been carried out by AVL 473C exhaust gas analyzer and AVL smoke meter.

#### 3.1. Performance analysis

Fig. 3 shows the brake thermal efficiency (BTE) of fuels used at different loads and different fumigation timings. Found that there is no significant change in BTE upto 70%. The considerable occurs only after the 70% load. It is found that the BTE of B20 is 7.15% lower than diesel at 100% load and the BTE of fumigated fuel is 9.36% lower than the diesel fuel at 100% load. It is simply because of less fuel supply at 1 ms injection timings. It is clear that the BTE at fumigation fuel at 5 ms is 6.7% higher than diesel and at 3 ms is 3.1% higher than the reference diesel fuel at 100% load. This is due to the pre evaporation of fumigation fuels which leads to better combustion. The better combustion is achieved by the fumigation fuel injected at 5 ms through the inlet manifold increases the flame propagation velocity.

Fig. 4 presents the variation of SFC with different loads. Specific fuel consumption (SFC) denotes the amount of fuel consumed per kW power and hour. It is seen that the SFC of fumigation fuel at 1 ms and 5 ms injection timings are 18.6% and 16.36% respectively higher than the diesel at 100% load. It is studied that the SFC of fumigation fuel at 5 ms is 18.6% higher than diesel at 100% load and 23 % higher than diesel at 80% load. The specific fuel consumption of all the fuels are higher at lower

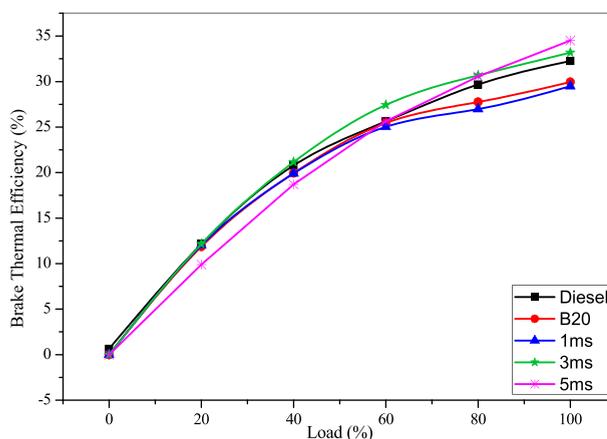
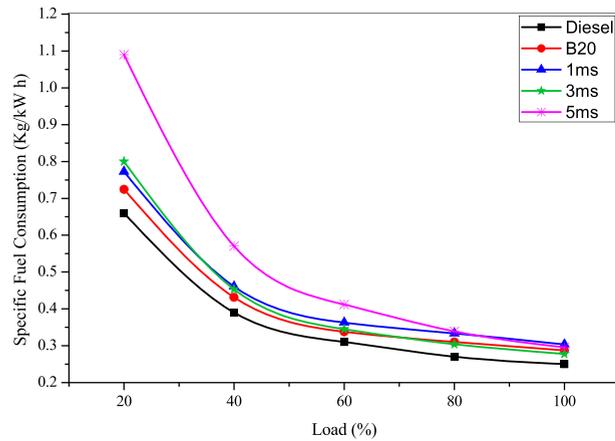


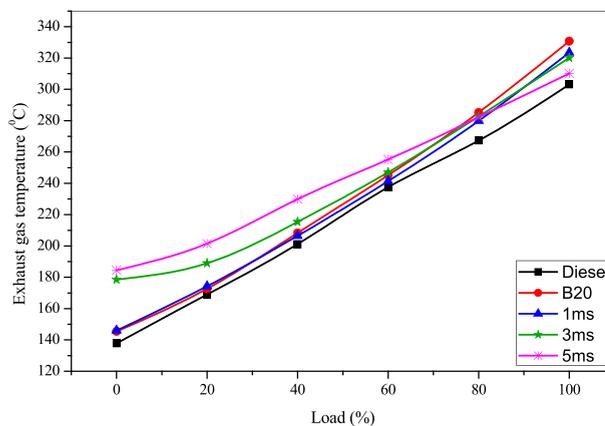
Fig. 3. Variation of Brake Thermal Efficiency with load.



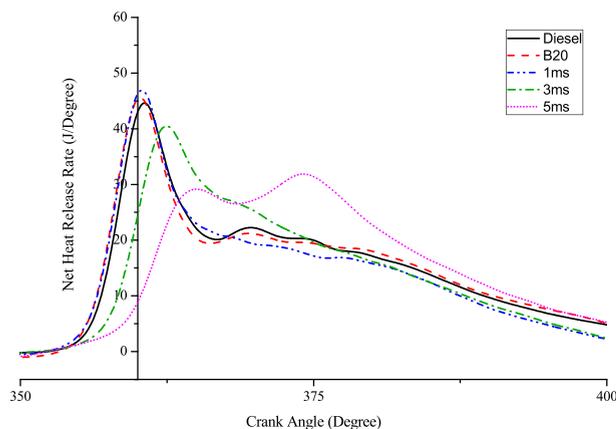
**Fig. 4.** Variation of Specific Fuel Consumption with load.

loads and considerable decrease occurs only after 40% loads and SFC is very narrow at 80% - 100% load. It is noted that the SFC of fumigation fuel at 5 ms takes is higher than all the fuels and fumigation fuel at 1 ms and 3 ms at lower load (20–50%) conditions. The SFC of reference diesel consumes very lower fuel than all other fuels at the lower load conditions. Therefore the fumigation fuel is very effective at the maximum load condition. This is simply because of the higher rate of evaporation.

**Fig. 5** shows that the exhaust gas temperature at different fumigation timings with respect to load. Found that the exhaust temperature of reference diesel is lower than all the fuels at all the load conditions. It is seen that the B20 blend gives 6% and 9.15% higher exhaust temperature than the diesel at 80% and 100% load respectively. This may be due to the breaking of molecular bonding which leads to rise the exhaust temperature. It is found that the fumigation fuels give lower exhaust gas temperature when compared with B20 at the 80–100% load. The fumigation fuel at 5 ms gives 9% lesser exhaust gas temperature than the B20 at 80% load. This is because of higher fuel supply which takes more heat for vaporization resulting lesser exhaust gas temperature.

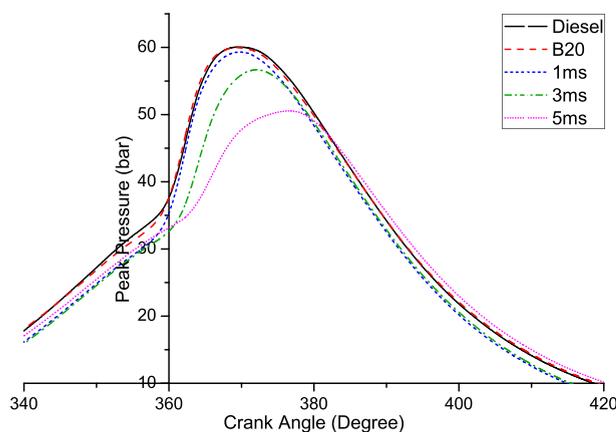


**Fig. 5.** Exhaust gas temperature vs load.



**Fig. 6.** Net heat release rate with crank angle at 80% load.

Fig. 6 shows that the variations of heat release rate with respect to crank angle for different fuels. It is observed that the net heat release of fumigation fuel (1-propanol) at 1 ms produces 2% higher than the reference diesel at crank angle of  $360^\circ$ . The maximum net heat release of fumigation fuel at 1 ms is due to the supply of less amount of fuel which makes better evaporation for combustion. The minimum net heat release is observed at 5 ms fumigation fuel. This is because of more quantity of fumigation fuel at 5 ms faces insufficient oxygen. Fig. 7 shows that the variation of cylinder peak pressure with respect to crank angle at different fuels. It is observed that the maximum cylinder peak pressure of diesel is 60 bar at  $370^\circ$  crank angle. The fumigation fuel (1-propanol) at 1 ms produces 1.2% lower peak pressure than the reference diesel at the same crank angle. The maximum cylinder peak pressure of 1 propanol at 1 ms is due to the supply of less amount of fuel during the injection timing 1 ms. It is Found that the cylinder peak pressure of 5 ms minimum than all the fuels. This may be due to supply of more quantity of fumigation fuel during 5 ms timing and the supply of more fuel at 5 ms faces insufficient oxygen for boosting the cylinder pressure.



**Fig. 7.** Effect of cylinder peak pressure on fumigation timing at 80% load.

### 3.2. Exhaust emissions

Fig. 8 indicates the variation of unburned hydrocarbon (HC) emission with respect to load. It is seen that the fumigation fuel (1-propanol) at 5 ms injection timing produces more percentage of HC at different load conditions and the maximum HC is observed at low load conditions. It is found that 1 propanol 1 ms produces 10% higher HC than the diesel. The reason may be the fumigation fuel is not properly vaporized due to insufficient heat. It is found that the diesel and B20 show lesser HC level than the fumigation fuel at different injection timings. Fig. 9 indicates the variation of carbon monoxide (CO) emission with respect to load. It is studied from the Fig. 9 that the fumigation fuel (1-propanol) injection timing at 5 ms produces more percentage of CO at different load conditions. It is also studied that the minimum level of CO is 0.38 % at 40% load condition. The reason may be the restriction of flow of oxygen from the atmosphere due to fumigation. Fig. 10 shows the variation of carbon dioxide (CO<sub>2</sub>) emission with respect to load. It is seen that the fumigation fuel at 5 ms injection timing produces minimum percentage of CO<sub>2</sub> at different load conditions. It is found that the minimum level of CO<sub>2</sub> is 9.3% at 80% load condition. This is simply because of the fumigation fuel is not properly combusted due to shortage of oxygen. Fig. 11 shows that the variation of excess oxygen with respect to load. It is found that the exhaust of fumigation fuel at 5 ms injection timing gives maximum excess oxygen percentage at different load conditions. It is also found the excess oxygen of fumigation fuel at 1 ms level is 4.1% lower than the diesel at 100% load condition. The reason may be supplied fumigation fuel at 1 ms is not properly combusted due to insufficient heat vaporization.

Fig. 12 shows the variation of nitrogen oxide (NO) with respect to load. It is studied that the fumigation fuel at 5 ms injection timing produces lesser NO percentage at different load conditions. Further, it is found that the NO level is

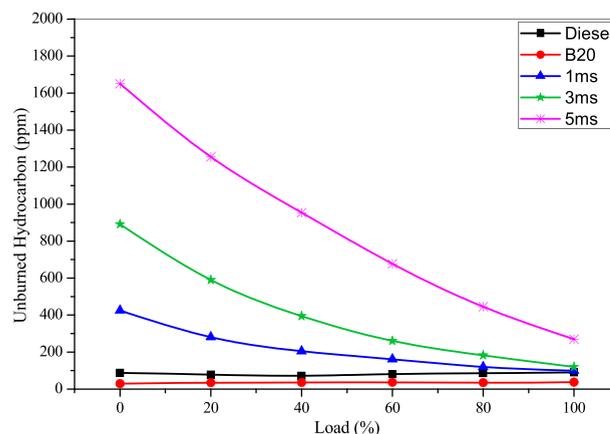


Fig. 8. Variation of exhaust hydrocarbon with load.

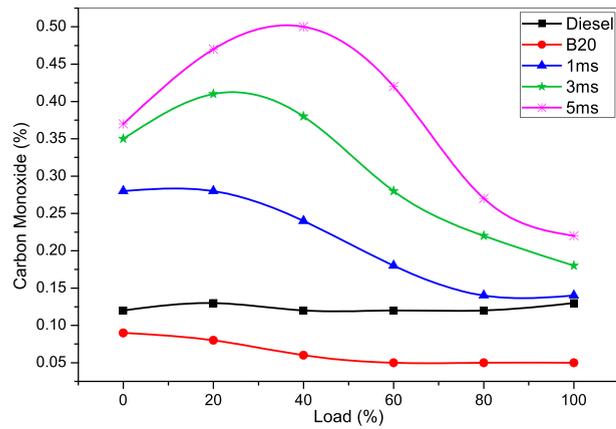


Fig. 9. Variation of carbon monoxide emission with load.

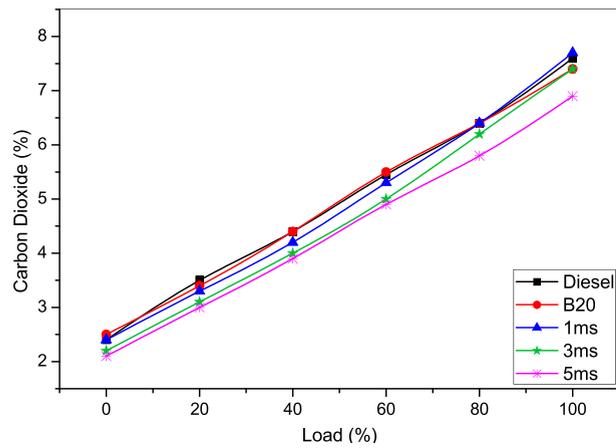


Fig. 10. Exhaust carbon Di Oxide vs loads.

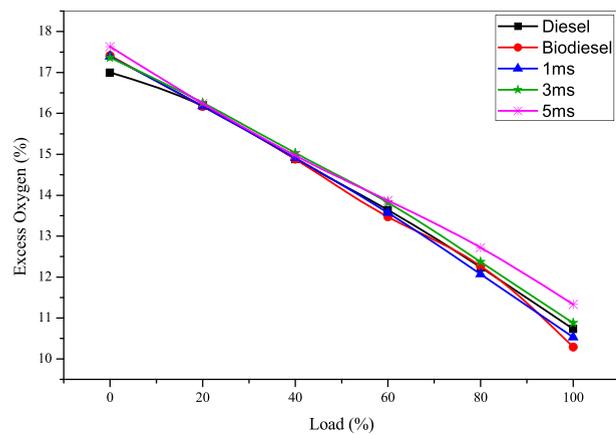
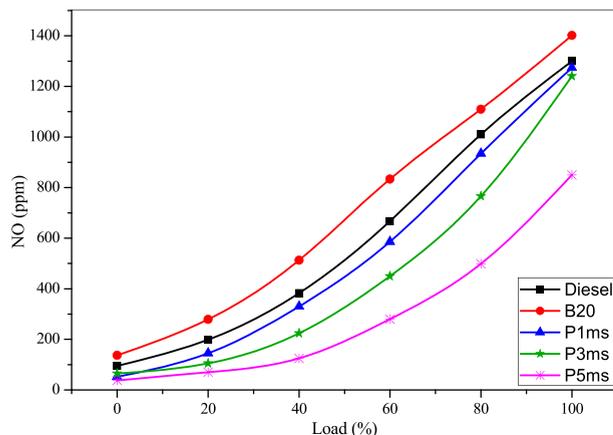
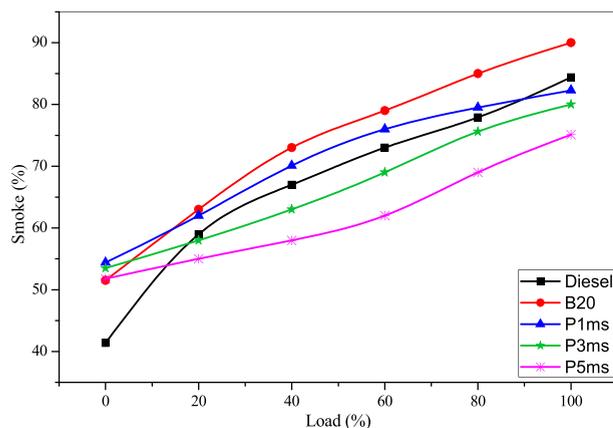


Fig. 11. Variation of excess oxygen with load.



**Fig. 12.** Variation of nitrous oxide with different percentage of loads.



**Fig. 13.** Smoke particulate with loads.

34.61% lower than the diesel at 100% load condition. The reason may be the supplied fumigation fuel is not properly combusted due to insufficient heat and requirement of temperature more than 1400 K for forming NO Zeldovich [28]. Fig. 13 indicates the variation of smoke with respect to load. Fig. 13 depicts the level of smoke with respect to load. The combustion of fumigation fuel at 5 ms injection timing gives lower smoke percentage at various load conditions. It is studied that the fumigation fuel at 5 ms produces 11 % lesser smoke than the diesel at 100% load condition.

#### 4. Conclusions

In this experimental analysis, the performance and emission characteristics of single cylinder four stroke diesel engine handling lemongrass biodiesel blended with 20% of biodiesel and 80% of diesel (B20) as primary fuel and 1-propanol as secondary fuel for fumigation were studied with different load conditions and at different

fumigation injection timings. The following are the observations made out of this experimental work:

The brake thermal efficiency of fumigation fuel at 5 ms is 6.7% higher than diesel and at 3 ms is 3.1% higher than the diesel fuel at 100% load. The SFC of fumigation fuel at 5 ms is 18.6% higher than diesel at 100% load and 23 % higher than diesel at 80% load. The B20 blend gives 6% and 9.15% higher exhaust temperature than the diesel at 80% and 100% load respectively. The net heat release of fumigation fuel (1-propanol) at 1 ms produces 2% higher than the reference diesel at crank angle of 360°.

The fumigation fuel (1-propanol) injection timing at 5 ms produces more percentage of CO at different load conditions. Also studied that the minimum level of CO is 0.38 % at 40% load condition. The NO level is 34.61% lower than the diesel at 100% load condition. The fumigation fuel at 5 ms injection timing produces minimum percentage of CO<sub>2</sub> at different load conditions. The minimum level of CO<sub>2</sub> is 9.3% at 80% load condition. The exhaust of fumigation fuel at 5 ms injection timing gives maximum excess oxygen percentage at different load conditions. The excess oxygen of fumigation fuel at 1 ms level is 4.1% lower than the diesel at 100% load condition. Therefore it is concluded that the fumigation effect on engine performance and emissions gives considerable favorable outcome at different injection timings and at 80%–100% load condition. The future work is required to optimize the fumigation fuel injection timing for optimum engine performance and reduced emissions.

## Declarations

### Author contribution statement

M. Vijayakumar: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

P. C. Mukesh Kumar: Performed the experiments; Analyzed and interpreted the data.

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### Competing interest statement

The authors declare no conflict of interest.

## Additional information

No additional information is available for this paper.

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